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U1S S1140

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EP 0412452 A2 US 4868040 A US 4732803 A
US 4681792 A

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UK CL (Edition M) B5N, F3C CP2
INT CL^5 F41H
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(54) Composite ballistic armour

(57) A rigid ballistic armour composite (10) which comprises (a) adjacent the strike face, a layer (11) containing synthetic fibres in a matrix of a first polymer and, laminated thereto, (b) adjacent the back face, a layer (12) containing ultra-high molecular weight polyethylene fibres in a matrix of a second polymer. The synthetic fibres may comprise aliphatic polyamide fibres such as polyamide [6, 6], aromatic polyester fibres such as polyethylene terephthalate, or aromatic polyamide fibres of lower ballistic performance than the polyethylene fibres.

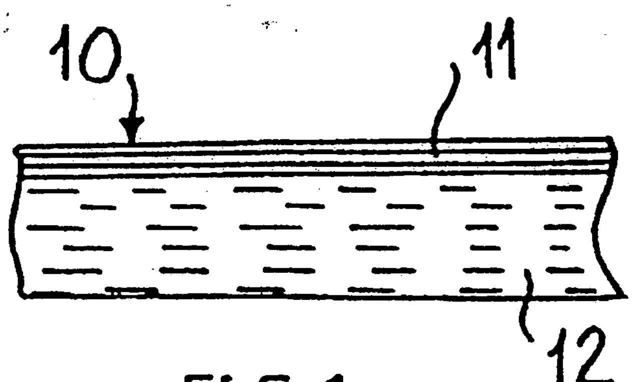

FIG.1

GB 2 276 935 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

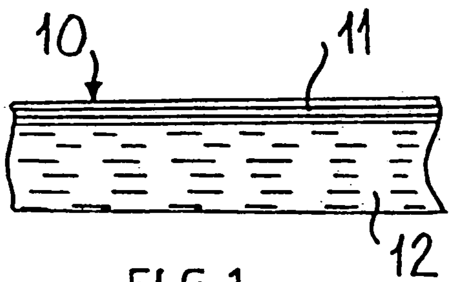
10
11
12

FIG.1

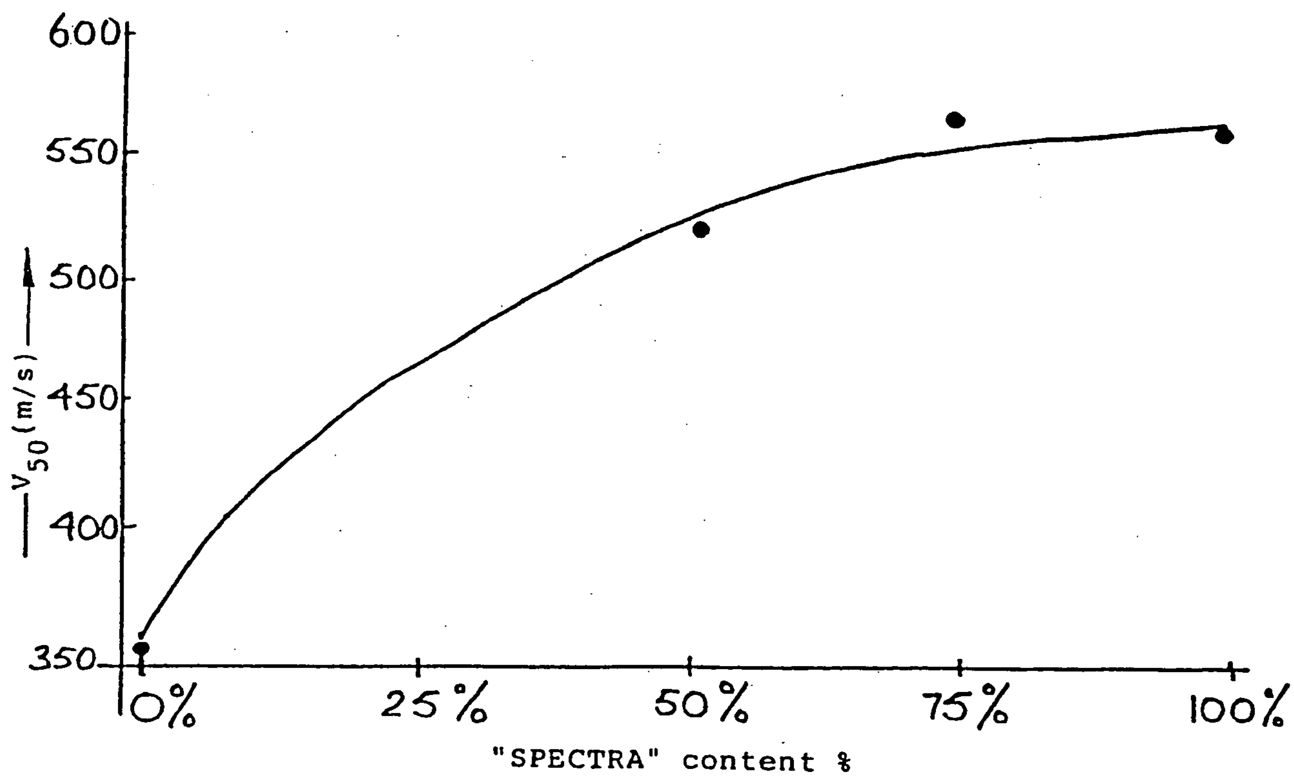
600
550
500
450
400
350
V_{50} (m/s)
0%
25%
50%
75%
100%
"SPECTRA" content %

FIG.3

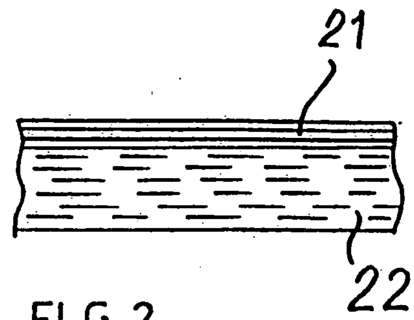
21
22

FIG. 2

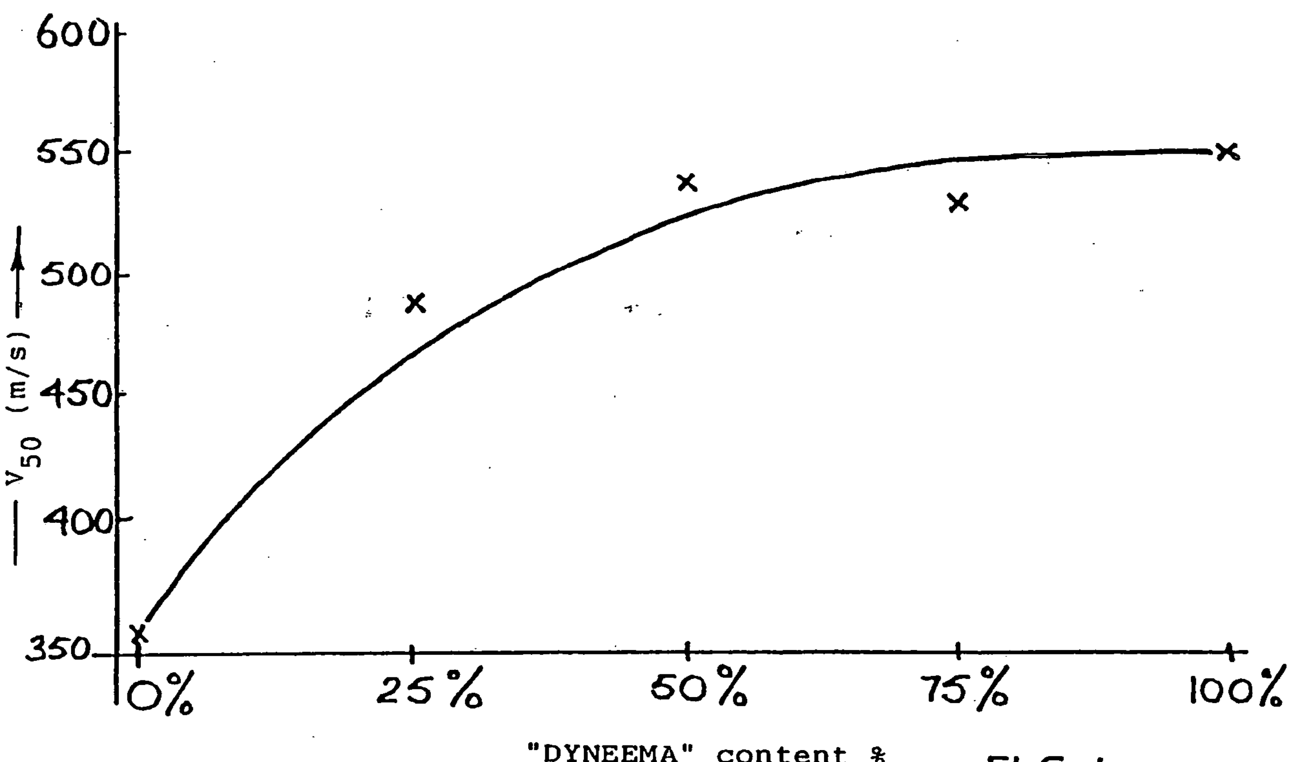
600
550
500
450
400
350
V50 (m/s)
0%
25%
50%
75%
100%
"DYNEEMA" content %

FIG. 4

Ballistic Resistant Composites

This invention relates to a ballistic armour composite, that is to say a rigid composite which comprises reinforcing fibre or fabrics embedded in a polymer matrix.

Polymer composites are gaining importance in ballistic protection for military and civilian personnel, due mainly to the high strength, stiffness, and elongation provided by man-made fibres. Such composites offer many advantages over metal armour, including high durability, light weight and low maintenance costs.

Various composites have been proposed in the past for use in ballistic protection. A commonly used composite comprises a laminated structure consisting of woven or knitted glass fibre structures embedded in various matrices such as for example epoxy resin, polyester resin or phenolic resin. In the main, prior known composites have comprised a single type of fibre as the reinforcement embedded in one or more polymer matrices.

A commonly used reinforcement for ballistic resistant composites are fabric layers made from aromatic polyamide fibres (often also called aramid or polyaramid fibres) of which "Kevlar" (a trademark of Du Pont), "Twaron" (a trademark of Enka) and "Technora" (a trademark of Teijin) are the most well known. Aromatic polyamide fibres and fabrics offer significantly better ballistic performance than glass fibre reinforced composites but compared with glass fibre reinforced composites are considerably more expensive.

Another suggested reinforcement for ballistic resistant composites are fabric layers made from ultra-high molecular weight (i.e. molecular weights greater than 1,000,000) polyethylene fibres of the type known as "Dyneema" (a trademark of DSM) and that known as "Spectra" (a trademark of Allied Signal Corporation). Dyneema and Spectra also have a

better ballistic performance than glass fibre reinforced composites and compared with glass fibre are more expensive.

The ballistic performance of various composites in terms of their resistance to penetration by projectiles may be tested and compared in many different ways. One convenient way, for example, is to fire a known sized projectile at samples of the composite and to record the velocity at which, theoretically, 50% of the projectiles penetrate the composite and the other 50% are stopped by the composite. This velocity is often referred to as the V_{50} velocity.

If one carries out ballistic performance tests on a lightweight composite comprising glass fibres embedded in, for example, a phenolic resin, one arrives at a much lower V_{50} velocity than one would achieve with a composite made using ultra-high molecular weight polyethylene fibres using the same test.

The design of a ballistic armour composite is a compromise between the weight, cost, ballistic performance and thickness of the composite, in relation to what the perceived threat is likely to be. In other words, if the threat is likely to be from small arms munitions, then one type of composite may be more suited than another, but if the perceived threat is from, for example, fragments of an artillery shell, then different composites may be more suited than those used for the small arms threat.

US Patent 2,697,054 (Dietz et al.) describes ballistic composites in which the substances with the greatest resistance to punching shear forces (that is, the better structural properties) are placed on the impact side and the substances which have the greatest properties of tensile strength and elongation (that is, the better ballistic properties) are placed towards the back side.

An aim of the present invention is to provide a hybrid

composite ballistic armour composite which has a good ballistic performance but is cheaper than one made with 100% ultra-high molecular weight polyethylene fibre reinforcement.

According to the invention there is provided a rigid ballistic armour composite which comprises fibre reinforcement in a polymer matrix, which includes (a) adjacent the strike face, a layer containing synthetic fibres in a matrix of a first polymer and, laminated thereto, (b) adjacent the back face, a layer containing ultra-high molecular weight polyethylene fibres in a matrix of a second polymer. Composites according to the invention are asymmetric composites.

Preferably the synthetic fibre is an aliphatic polyamide fibre (e.g. polyamide [6,6]) or an aromatic polyester fibre (e.g. polyethylene terephthalate). Alternatively the synthetic fibre may be an aromatic polyamide of lower ballistic performance than the polyethylene fibres.

The first and second polymers may be the same polymer material. Alternatively the first and second polymers may be different polymer materials.

The matrix materials may be selected from the group of polymer materials consisting of the following, although the invention is not limited thereto:- phenolic resins, polyester resins, epoxy resins, vinylester resins, polyetheretherketones (PEEK), polyethersulphones (PES), polysulphones, polyetherimides (PEI), polyarylketones (PAK), polyethylene (PE), polypropylene, polycarbonates, polystyrene and polyacrylates. Alternatively, the polymer matrix material for the back layer may be a thermoplastic rubber such as a styrene-butadiene-styrene (SBS) or polyurethane (PU) rubber.

The reinforcement in a composite according to the invention may comprise a plurality of plies or layers of fibres in the form of filaments or yarns which may be

dispersed unidirectionally or multi-directionally, particularly in the backing layer. However the preferred form of reinforcement is in the form of a fabric which may be a woven fabric, or a non-woven fabric, or a knitted fabric. Preferably the reinforcement comprises a plurality of plies of such fabrics.

A composite according to the invention may conveniently be made by lamination of prepregs, that is to say fibre plies impregnated with thermosetting or thermoplastic polymer resin. The areal weight of a prepreg containing a synthetic fibre fabric is preferably in the range 100 to 600 grams per square metre. The areal weight of a prepreg containing an ultra-high molecular weight polyethylene fibre fabric is preferably in the range 100 to 400 grams per square metre.

Of the total fibre reinforcement in the composite, the synthetic fibre may amount to about 20 to about 80 percent, preferably about 20 to about 50 percent, by weight, and the ultra high molecular weight polyethylene fibre correspondingly to about 80 to about 20 percent, preferably about 80 to about 50 percent, by weight.

The areal weight of a composite according to the invention may be in the range 1 to 100 kilograms per square metre. For use in personal protection armour, the areal weight is preferably in the range 4 to 20 kilograms per square metre. When used for personal protection, a composite according to the invention may be incorporated as rigid inserts or tiles in pockets in a garment. A composite according to the invention may also be used for the manufacture of protective helmets and portable personal shields. For vehicle protection, the areal weight of the composite is preferably in the range 20 to 80 kilograms per square metre. When used for vehicle protection, a composite according to the invention may be used in the manufacture of the vehicle body itself or as a lining inside a conventional vehicle body to prevent injury from spalled fragments.

The invention further provides a method of making a rigid ballistic armour composite including the steps of:

(1) providing a first prepreg which consists of a ply of synthetic fibres impregnated with a first polymer;

(2) stacking a plurality of the first prepregs to form a stacked facing layer;

(3) providing a second prepreg which consists of a ply of ultra-high molecular weight polyethylene fibres impregnated with a second polymer;

(4) stacking a plurality of the second prepregs to form a stacked backing layer;

(5) locating the stacked facing layer upon the stacked backing layer to form a stacked body; and

(6) subjecting the stacked body to heat and pressure thereby forming the rigid ballistic armour composite.

It may be desired to include an adhesive layer between the strike face layer and the backing layer, particularly if the first and second polymer resins are different materials.

The invention further provides an alternative method of making a rigid ballistic armour composite including the steps of:

(1) providing a first prepreg which consists of a ply of synthetic fibres impregnated with a first polymer;

(2) stacking a plurality of the first prepregs to form a stacked facing layer;

(3) subjecting the stacked facing layer to heat and pressure to form a facing laminate;

(4) providing a backing laminate which consists of plies of ultra-high molecular weight polyethylene fibres in a matrix of a second polymer; and

(5) adhering the facing laminate and the backing laminate together by means of an adhesive thereby forming the rigid ballistic armour composite.

The backing laminate may be formed by subjecting a stack of prepregs to heat and pressure. Alternatively, in a method which may be preferred, it may be formed by subjecting to heat and pressure a stacked layer which consists of plies of the ultra-high molecular weight polyethylene fibres interleaved with sheets of low density polyethylene (LDPE) film. In this alternative method, the combined areal weight of a single ply of ultra-high molecular weight polyethylene fibres and a single sheet of low density polyethylene film is preferably in the range 100 to 400 grams per square metre.

Composites in accordance with the invention are especially suitable for use in ballistic armour intended for protection against impact from munitions fragments represented by 1.1 gram fragment simulating projectiles.

It has surprisingly been found that the ballistic performance of composites according to the invention is markedly superior to that of composites which have ultra-high molecular weight polyethylene fibre reinforcement in the strike face layer and synthetic fibre reinforcement such as polyamide [6,6] fibre in the backing layer. One would expect at first sight that better properties would be obtained by having the reinforcement of superior ballistic properties in the strike face layer and that of inferior ballistic properties in the backing layer.

The present invention will now be further described, by way of examples, with reference to the accompanying drawings in which:-

Figures 1 and 2 show schematic cross sections through two composites constructed in accordance with the present invention, and

Figures 3 and 4 show respectively the ballistic performance of the composites shown in Figures 1 and 2.

Fragment V_{50} testing was carried out in accordance with the UK Specification UK/SC/4697 using 1.1 g fragment simulating projectiles.

Figure 1 shows a composite constructed in accordance with the present invention in the form of a unitary rigid composite 10 comprising two portions 11 and 12. Portion 11 defines the strike face of the composite (that is to say the strike face is the surface which would normally face towards the projectiles directed at the composite), and the portion 12 defines a backing portion.

The strike face-defining portion 11 comprises a stack of fabrics made from aliphatic polyamide fibres such as polyamide [6,6] (Nylon 6,6), which are pre-impregnated with phenolic resin. A suitable phenolic resin is that manufactured by Borden (UK) Limited under their reference No.SC1008P or that formulated by Courtaulds Aerospace Limited under their reference PH16 (this is a polyvinylbutyral modified phenolic resin).

The Nylon 6,6 yarn used was that made by ICI Limited under ICI reference T1142 (used for the warp threads). This yarn was 940 decitex, and comprised 140 filaments. For the weft yarn, an ICI yarn reference T126 was used. This yarn was 950 decitex, and comprises 140 filaments. The approximate filament diameter of both yarns was 27 micron.

The yarns were woven by Courtaulds Aerospace Limited (their ref. DO594) to produce a woven fabric comprising 13.7 ends/cm and 13.0 picks/cm having a nominal areal weight of 260 g/m². The fabric was scoured after weaving. The fabric was impregnated with 18 ± 2% by weight of phenolic resin to give a prepreg of 317 g/m².

The backing portion 12 comprises a plurality of fabric layers made from ultra-high molecular weight polyethylene fibres, that is to say polyethylene with molecular weight of greater than 1,000,000. The preferred polyethylene is that known by the trademark Dyneema (a trademark of DSM) or that known by the trade mark Spectra (a trademark or Allied-Signal Corporation) embedded in a polymer resin matrix.

Suitable polyethylene yarn is that manufactured by Allied-Signal Corporation to their yarn reference Spectra 900. This is a 1200 denier yarn comprising 118 filaments of 30 micron diameter. The fabric used for the backing portion was supplied by Allied-Signal Corporation - their reference style 903 - and comprised a plain weave with 21 ends/inch (8.3 ends/cm) and 21 picks/inch (8.3 picks/cm) and had a nominal areal weight of 235 g/m². The backing portion was impregnated with 20% by weight vinylester resin to give a prepreg of 290 g/m².

The unitary body composite can be made in two ways. Either the two portions 11, 12 may be moulded separately and adhesively bonded together using for example a polysulphide adhesive of the type known as Bostik 2114 (a trademark of Bostik Limited), or the portions 11, 12 can be laid up in a single mould and moulded together.

Referring to Figure 3 there is shown the ballistic performance of the composite shown in Figure 1. From Figure 3 it will be seen that by the replacement of Spectra fabric with up to 50% of the relatively cheaper layers of nylon (compared to the cost of the Spectra fabric) one can produce

a composite which has a ballistic performance close to that of a composite made solely with Spectra 900 reinforcement. Such startling results particularly would not be expected in view of the fact that the fragment V_{50} velocity for a composite comprising wholly Nylon 6,6 reinforcement in phenolic resin is of the order of 355 metres per second, whereas that for a composite comprising 100 percent Spectra reinforcement in the composite is of the order of 560 metres per second. Clearly, from Figure 3 it will be appreciated that the more nylon reinforcement that is present in the whole composite the less will be the V_{50} velocity for that composite for a given perceived threat, but one can trade off ballistic performance against cost and this could be particularly important when one bears in mind that the cost of the nylon is significantly less than that of the Spectra 900.

Referring to Figure 2 there is shown a further composite constructed in accordance with the present invention. In the composite of Figure 2 the backing portion 22 comprises a plurality of fabric layers made from ultra-high molecular weight polyethylene yarn of the type known as Dyneema SK66. The Dyneema yarn SK66 (a 400 Denier yarn) was woven to give a 3/1 satin weave fabric with an areal weight of 150 g/m^2.

The first portion 21 of the composite of Figure 2 was made in exactly the same way as the portion 11 shown in Figure 1 and comprised nylon reinforcement in phenolic resin.

The backing portion 22 was prepared by interleaving low density polyethylene film (18% by weight of total) with the Dyneema fabric and consolidating the layers in a heated mould under pressure.

The first portion 21 was laid up separately from the backing portion 22 and the two portions 21, 22 were glued together using a polysulphide adhesive of the type known as Bostik 2114 (Bostik is a trademark of Bostik Limited).

Referring to Figure 4 there is shown the ballistic performance of the composite shown in Figure 2. Here again the addition of relatively cheaper layers of nylon enables one to make a composite which has a good ballistic performance. As stated above the fragment V_{50} velocity for a composite made wholly of nylon reinforcement in phenolic resin is of the order of 355 metres/second whereas that for a composite comprising 100% Dyneema reinforcement is of the order of 555 metres/second.

From Figure 4 it will be seen that the substitution of up to say 50% nylon reinforcement for the Dyneema reinforcement lowers the ballistic performance only slightly but for a given threat, one can trade off ballistic performance against cost and still achieve an acceptable performance for a given perceived threat.

In a yet further embodiment (not illustrated) the Nylon 6,6 is replaced by a fabric woven from an aramid fibre of relatively lower performance than that used in the backing layer. For example the first portion defining the strike face may comprise Kevlar 29 and the backing portion polyethylene fibre (e.g. Spectra or Dyneema).

In the above examples nylon and aramid fibres have been used in the first portion. It is to be understood that reinforcement made of other types of fibres may be used in the first portion such as, for example, polyester, (e.g. poly(ethylene terephthalate)) may be used to give a first portion 11 of lower ballistic performance than that of the backing portion 12.

The preferred form of the reinforcement is a fabric which may be a knitted, woven or non-woven fabric. Furthermore, each prepreg layer could be in the form of unidirectional or multi-directional fibres. Indeed each prepreg could comprise a plurality of layers of fabric, unidirectional fibres or multi-directional fibres. The unidirectional fibres in one layer

may lie at an angle to those in adjacent layers. The lay up of such reinforcement is well known in the art of making composite materials.

CLAIMS

1. A rigid ballistic armour composite which comprises fibre reinforcement in a polymer matrix, wherein the composite includes (a) adjacent the strike face, a layer (11) containing synthetic fibres in a matrix of a first polymer and, laminated thereto, (b) adjacent the back face, a layer (12) containing ultra-high molecular weight polyethylene fibres in a matrix of a second polymer.

2. A composite according to claim 1, wherein the synthetic fibres are aliphatic polyamide fibres or aromatic polyester fibres.

3. A composite according to claim 2, wherein the synthetic fibres are polyamide [6,6] fibres.

4. A composite according to claim 1, wherein the synthetic fibres are aromatic polyamide fibres of lower ballistic performance than the ultra-high molecular weight polyethylene fibres.

5. A composite according to any one preceding claim, wherein the first polymer and the second polymer are the same material.

6. A composite according to any one of claims 1 to 4, wherein the first polymer and the second polymer are different materials.

7. A composite according to any one preceding claim, wherein the first polymer is selected from phenolic resins, polyester resins, epoxy resins, vinylester resins, polyetheretherketones (PEEK), polyethersulphones (PES), polysulphones, polyetherimides (PEI), polyarylketones (PAK), polyethylene (PE), polypropylene, polycarbonates, polystyrene and polyacrylates.

8. A composite according to any one preceding claim, wherein the second polymer is selected from phenolic resins, polyester resins, epoxy resins, vinylester resins, polyetheretherketones (PEEK), polyethersulphones (PES), polysulphones, polyetherimides (PEI), polyarylketones (PAK), polyethylene (PE), polypropylene, polycarbonates, polystyrene and polyacrylates, styrene-butadiene-styrene (SBS) rubbers and polyurethane (PU) rubbers.

9. A composite according to any one preceding claim, wherein layer (a) contains a plurality of plies of the synthetic fibres.

10. A composite according to claim 9, wherein the plies of synthetic fibres in layer (a) comprise woven, knitted or non-woven fabrics.

11. A composite according to claim 9 or claim 10, wherein the areal weight of each such ply in layer (a) together with the matrix of first polymer associated therewith is in the range 100 to 600 grams per square metre.

12. A composite according to any one preceding claim, wherein layer (b) contains a plurality of plies of the ultra-high molecular weight polyethylene fibres.

13. A composite according to claim 12, wherein the plies of ultra-high molecular weight polyethylene fibres comprise woven, knitted or non-woven fabrics.

14. A composite according to claim 12, wherein the plies of ultra-high molecular weight polyethylene fibres comprise unidirectional arrays of filaments or yarns.

15. A composite according to claim 14, wherein the ultra-high molecular weight polyethylene fibres are disposed in different directions in adjacent plies.

16. A composite according to any one of claims 12 to 15, wherein the areal weight of each such ply of ultra-high molecular weight polyethylene fibres together with the matrix of the second polymer associated therewith is in the range 100 to 400 grams per square metre.

17. A composite according to any one preceding claim, wherein its areal weight is in the range 1 to 100 kilograms per square metre.

18. A composite according to claim 17, wherein its areal weight is in the range 4 to 20 kilograms per square metre.

19. A composite according to claim 17, wherein its areal weight is in the range 20 to 80 kilograms per square metre.

20. A method of making a rigid ballistic armour composite including the steps of:

(1) providing a first prepreg which consists of a ply of synthetic fibres impregnated with a first polymer;

(2) stacking a plurality of the first prepregs to form a stacked facing layer;

(3) providing a second prepreg which consists of a ply of ultra-high molecular weight polyethylene fibres impregnated with a second polymer;

(4) stacking a plurality of the second prepregs to form a stacked backing layer;

(5) locating the stacked facing layer upon the stacked backing layer to form a stacked body; and

(6) subjecting the stacked body to heat and pressure thereby forming the rigid ballistic armour

composite.

21. A method of making a rigid ballistic armour composite including the steps of:

(1) providing a first prepreg which consists of a ply of synthetic fibres impregnated with a first polymer;

(2) stacking a plurality of the first prepregs to form a stacked facing layer;

(3) subjecting said first stacked layer to heat and pressure to form a facing laminate;

(4) providing a backing laminate which consists of plies of ultra-high molecular weight polyethylene fibres in a matrix of a second polymer; and

(5) adhering said first laminate and said second laminate by means of an adhesive.

22. A method according to claim 21, wherein the backing laminate is made by subjecting to heat and pressure a stack of the plies of ultra-high molecular weight polyethylene fibres interleaved with sheets of low density polyethylene (LDPE) film as the second polymer.

23. A method according to claim 21, wherein the backing laminate is made by subjecting to heat and pressure a stack of prepregs, each of which comprises ultra-high molecular weight polyethylene fibres impregnated with the second polymer.

24. A rigid ballistic armour composite substantially as herein described with reference to Figure 1 or Figure 2 of the accompanying drawings.

25. A method for the manufacture of a rigid ballistic armour composite substantially as herein described with reference to Figure 1 or Figure 2 of the accompanying drawings.

Patents Act 1977
Examiner's report to the Comptroller under Section 17
(The Search report)

-17-

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Relevant Technical Fields

(i) UK Cl (Ed.M) F3C CP2 B5N

(ii) Int Cl (Ed.5) F41H

Search Examiner
PAUL GAVIN

Date of completion of Search
20 JUNE 1994

Databases (see below)
(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE: WPI

Documents considered relevant following a search in respect of Claims :-
ALL

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
X	EP 0412452 A2	(TOYO BOSEKI) whole document	1 at least
X	US 4868040	(CANADIEN P & D) whole document	1 at least
X	US 4732803	(SMITH) whole document	1 at least
X	US 4681792	(ALLIED) whole document	1 at least

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